

Reflectorized Sheeting Material for Overhead Signs

Performance and State of the Art Review

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ABSTRACT

This report examines the relationships between luminance of an overhead sign and its legibility for the purpose of assisting cost-effectiveness evaluation of the illumination of overhead signs. The report also aids review of present practices and helps to determine the minimum luminance requirement for legibility of overhead signs.

A field study, involving night-time visual assessment and luminance measurements, was carried out by the Research and Development Branch. The study was structured to obtain motorist-oriented views and responses to a variety of lighting conditions and anomalies, to collect corresponding luminance measurements, and to ascertain the optical principles which govern the characteristics of retro-reflectorized sheeting.

Conclusions are drawn, both from the collected data and observation and from the literature review, recommending minimal luminance levels, proposals for changes to present illumination practice and requirements for the development of design standards for headlight illuminated overhead signs.

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1/ INTRODUCTION

1.1 The Problem

Since the early 1960s, MTC has illuminated overhead signs with supplementary lighting. At the present time there are over 2200 light fixture locations in the Central Region and this number is increasing at the rate of 140 per year.

The annual cost of maintaining these luminaries amounts to \$100 000. The yearly energy consumption raises this amount by an additional \$65 000.

It is estimated that in 1983, in Central Region, the combined annual capital expenditure and maintenance cost will be in the vicinity of \$255 000.

With the painted or vinyl faced overhead signs, the need for supplementary lighting was essential. However, since 1975 the emergence of and experience with retro-reflective sign facing materials (High Intensity Grade) has demonstrated the need for a review of the supplementary lighting practice.

It is the aim of this report to determine whether supplementary illumination of the overhead signs can be discontinued without adversely affecting legibility and comprehension as well as to determine the luminance level requirements.

1.2 Background

As part of the re-evaluation of the need for the illumination of the overhead signs, the Electrical Design and Development Section requested the Research and Development Branch to carry out a study to determine the differences in legibility exhibited by the overhead signs covered with Engineering Grade and High Intensity Grade reflective sheeting.

The study was to ascertain luminosity levels for different illumination conditions, identify contrasts between background and legend, identify the degree of illumination by various sources such as sign illumination, ambient light and car headlights, and the legibility of the message.

At about the same time the Maintenance Services Office also undertook a series of night-time visual inspections by several groups of two-men observer teams. The Research and Development Branch was asked to participate as one of the teams. The scope of these inspections was to obtain the motorist-oriented view of the variety of lighting conditions while navigating a prescribed route at usual speed and at the same time attempting to identify and classify the various anomalies. The routes were selected to include a range of illumination irregularities such as completely shut-off, reduced and fully illuminated signs, as well as signs with some of their luminaries burned out.

In order to avoid duplication as well as to analyze the same group of overhead signs, it was agreed to carry out the two studies concurrently.

This report documents the observations and luminance measurements carried out by Research and Development Branch. It also includes the analysis into the basic principles which govern the characteristics of the retro-reflective sheeting material, a review of up-to-date literature dealing both with illumination of overhead signs and with the state-of-the-art in general and an outline of recommendations concerning illumination practices and research needs.

2/ STUDY PROCEDURE AND INSTRUMENTATION

The objectives of this study were to ascertain the luminosity levels on highway signs which have different amounts of illumination and ambient lighting.

The selected signs are located along the major freeways in the vicinity of Metropolitan Toronto. The exact sign locations and other details are outlined in Appendix A.

The measurements were taken with a Pritchard Spectre Photometer model No. 1980A, as shown in Figure 1. This instrument is capable of measuring a field of view (angle of acceptance) ranging from $0^{\circ}2'$ to $3^{\circ}00'$. It has a direct digital readout in candelas per square metre with a sensitivity range from 10^{-4} to 10^8 cd/m². The instrument has an internal standardized calibration capability and can be operated on internal and external power supply.

The two-man crew consisted of a driver who took notes and photometer readings and the operator of the photometer who positioned the camera and operated its controls. A 1980 Plymouth Horizon and a 1974 Buick Apollo were used as test vehicles to supply headlight illumination. The test vehicle was positioned on the right-hand shoulder approximately 100 m in front of the sign and from this location the luminance measurements of the legend and the background were taken by the passenger through the windshield. Also noted were the legibility of the sign, colours of the background and the legend and any noticeable irregularities. All the observations were recorded under the following illumination conditions:

- 1/ With ambient light only (at certain locations these data could not be obtained due to extremely heavy and continuous traffic).
(Note: - Ambient illumination included sign lighting, if existing.)
- 2/ Ambient illumination plus headlights of the test vehicle.
(Note: - Test vehicle headlights were on low beams only.)
- 3/ Combination of ambient illumination plus platoon of cars moving on the roadway.
- 4/ Combination of ambient illumination, road traffic headlights and

headlights of test vehicle.

The luminance readings were taken between the hours of 21:00 and 24:00 and only during clear weather conditions.

For evaluating the legibility of the sign, a distance of 100 m was chosen as being representative for reading and to accommodate the angle of acceptance when taking the legend measurements.

The results are shown in Table 1 and Figure 2. The qualitative assessments of the visibility conditions do not parallel the quantification of luminosity but seem to peak before maximum luminance values. This is primarily because best visibility was experienced at those signs which have low ambient illumination resulting in minimized glare on the sign and high luminance generated by low headlight beams to provide sufficient contrast values between the legend and the background.

It was also observed that when a sign was located in such a way that the road alignment did not facilitate the illumination of the sign by the vehicle headlights. Generally such locations were found in two situations:

- where the roadway which was bending toward the left while vehicle headlights at that point are slanted toward the left while vehicle headlights at that point are slanted towards the right, and
- on vertical curves when the sign was located on the up-grade immediately following the sag of the vertical curve.

The above observation points out that the criteria for the location of overhead signs should also include the influences and effects of roadway lighting and roadway alignment.

3/ RETRO-REFLECTIVE SHEETING MATERIAL

3.1/ General Outline

The material analyzed in this report is the "Scotchlite" brand reflective sheeting series 2870, 3870 and 5870, manufactured by the 3M Company. The material specifications are outlined in the manufacturer's production bulletin [11].

The sheeting shown in Figure 3A is made up of spherical glass beads which are set in an opaque synthetic resin base which forms a mirrored surface at the point of contact, as illustrated schematically by Figure 3C. The beads are approximately 0.02 mm to 0.05 mm ($20\mu\text{m}$ to $50\mu\text{m}$) in diameter and are covered with a layer of transparent plastic which acts as a protective coating and colouring surface. This plastic layer is attached to the resin along a hexagonal honeycomb pattern to provide a uniform distribution of stresses between the two layers. This contact surface does not contain glass beads, consequently, it reflects the incidental light in a conventional manner.

The beads are spread evenly across the surface of the resin in a uniform layer one bead thick. Some defective beads which can be found, and the occasional gaps or voids -- as seen in the enlargement (100 X) in Figure 3B -- together with the hexagonal strips, reflect the incidental light also in the conventional manner. The honeycomb contact surface and the bead gaps amount to 15% of the total area, thus reducing the efficiency of retro-reflectivity to approximately 85%.

3.2/ Optical Principles

In accordance with the principles of reflection and refraction at spherical surfaces, the optical concept of the retro-reflective sheeting is illustrated in the schematic diagram in Figure 4. As a ray of light from an outside source hits the surface of the bead at point 'A' with an incident angle ' α_i ' it is refracted as it enters the bead with the angle of refraction ' α_r '. The mirrored surface at point 'B' completely reflects the beam back through the bead and as the ray emerges from the bead at 'C' it undergoes an additional refraction.

Adding all the deviations in the path of the ray produces the total angle 'D₁', as defined in Figure 4. This total deviation can be expressed in the following terms:

$$D_1 = \alpha_j - \alpha_r + 180^\circ - 2\alpha_r + \alpha_j - \alpha_r$$

or

$$D_1 = 180^\circ + 2\alpha_j - 4\alpha_r$$

The divergence angle can be defined as the difference between the incidence angle, and the exit angle. This divergence angle, 'ζ' as it is termed in specifications [11], is the 180° supplement of D₁ and can be expressed as:

$$\zeta = 4\alpha_r - 2\alpha_j \quad (1)$$

Differentiating Equation 1 with respect to 'α_j',

$$\frac{d\zeta}{d\alpha_j} = \frac{4d\alpha_r}{d\alpha_j} - 2 \quad (2)$$

Assuming 'μ' as the index of refraction of the glass bead, then the relationship between the angle of incidence and angle of refraction is:

$$\sin \alpha_j = \mu \sin \alpha_r \quad (3)$$

Differentiating equation 3 with respect to α_j,

$$\cos \alpha_j = \mu \cos \alpha_r \frac{d\alpha_r}{d\alpha_j} \quad (4)$$

Substituting equation 4 into 2,

$$\frac{d\zeta}{d\alpha_j} = \frac{4 \cos \alpha_j}{\mu \cos \alpha_r} - 2 \quad (5)$$

For ζ to be maximum,

$$\frac{d\zeta}{d\alpha_j} = 0$$

$$\text{Then: } \mu \cos \alpha_r = 2 \cos \alpha_i \quad (6)$$

$$\text{Squaring 6: } \mu^2 (\cos^2 \alpha_r) = 4 \cos^2 \alpha_i \quad (7)$$

$$\text{Squaring 3: } \alpha^2 (\sin^2 \alpha_r) = \sin^2 \alpha_i \quad (8)$$

Adding 7 & 8:

$$\mu^2 (\sin^2 \alpha_r + \cos^2 \alpha_r) = \sin^2 \alpha_i + 4 \cos^2 \alpha_i \quad (9)$$

$$\mu^2 = 1 + 3 \cos^2 \alpha_i$$

$$\cos^2 \alpha_i = \frac{\mu^2 - 1}{3}$$

$$\text{Then } \alpha_{i \text{ max}} = \arccos \sqrt{\frac{\mu^2 - 1}{3}} \quad (10)$$

$$\alpha_{r \text{ max}} = \arcsin \left(\frac{\sin \alpha_{i \text{ max}}}{\mu} \right) \quad (11)$$

$$\zeta_{\text{max}} = 4 \alpha_{r \text{ max}} - 2 \alpha_{i \text{ max}} \quad (12)$$

The meaning derived from Equations 10, 11 and 12 is that all the illumination falling on the beads will be reflected back towards the light source along a path delineated by a conical shape originating at the sign with the maximum angle of the cone $\zeta < \zeta_{\text{max}}$ as shown in Figure 5. The value of ζ_{max} is dependent on ' μ ', the index of refraction of the glass beads. The relationship between ' μ ' and ζ_{max} is shown in Figure 6.

For ordinary glass, the index of refraction is in the vicinity of 1.6. Assuming that the index of refraction of the glass beads is also 1.6, then the maximum path difference between the incident and the reflected light will be equal to or less than 15° . The importance of this finding is that it shows that the retro-reflective signs can be illuminated with a variety of incident angles yet most of the light is reflected towards the source within a narrow core of $\zeta_{\text{max}} < 15^\circ$.

On the roadway, when a driver observes an overhead sign, which is illuminated by his own vehicle headlights, the angle of observation (i.e., angle between his direction of view and the direction of illumination) is generally smaller than $\zeta_{\max}$ as shown in Figure 7. This is the reason why the luminance values in Table 1 are significantly larger when the sign was illuminated by the headlights of the test vehicle.

Of course, a portion of the light falling on the sign is not retro-reflected -- for example, the light falling on the surface which is not covered by glass beads or which is falling on the beads with glancing angle (α_i close to 90°). This efficiency loss is approximately 15 to 20%.

Finally, there is also the influence of the plastic surface layer, the effects of which have not been accounted for in the above description.

4/ ANALYSIS AND INTERPRETATION OF FINDINGS

A large portion of this report was devoted to the acquisition of data by means of an up-to-date and detailed literature review.

The major portion of the relevant information was extracted from studies which have been published within the last decade. It seems that most of these studies were undertaken in order to resolve a specific problem encountered by the practitioners of illumination; consequently, they have a narrow field of investigation. Also it seems that, in order to reduce resource consumption and costs, the scope of the studies are narrowed to minimize the complexity of inter-relationships and cross-impacts between all the factors affecting sign legibility which must be determined during a broad and comprehensive investigation.

A condensed review of the selected publications is outlined in Appendix 'B'.

One of the predominant findings emerging from the literature review is the variation in priority given by the different researchers to the factors utilized in the assessment of sign luminosity. The differences in approach occur not only with utilization of materials but also in the design aspects and maintenance practice and policies.

The differences seem to arise partly from local conditions, such as climate, and budget constraints, and partly from the continual innovations occurring in the state-of-the-art, which indicates that the discipline has not yet reached a complete state of maturity.

There is a multitude of variables which tend to influence the legibility of overhead signs. Factors such as luminance levels of the legend and the background, contrast, legend and background dimensions, colour combinations, sign position vis-a-vis the road alignment, ambient illumination, and traffic speed all contribute to and affect in varying degrees the legibility and comprehension of the signs.

Because of limited terms of reference and resources, this study dealt only with the collection of luminance values and qualitative perception for an existing group of overhead signs and analyzed these data in the

light of the information extracted from the literature and existing practices.

A temporary breakdown of the Pritchard Photometer precluded luminance measurements of all the signs with both the test vehicles; nevertheless, sufficient data were collected to complete an analysis for the development of preliminary guidelines and recommendations.

The measurements were made mainly of retro-reflective signs under somewhat restrictive conditions (very heavy traffic) which did not permit the full achievement of all study objectives (i.e., measurements of ambient luminance on 401 could not be done due to constant uninterrupted traffic flow).

The following are some of the outstanding findings which have been based on the field investigations as shown in Table 1 and Figure 2 and on data collected from other sources:

- Visual observations have generally shown that overhead signs, both with and without supplementary illumination, when illuminated with low beam headlights of the test vehicle from a distance of 100 m provide sufficient luminance for the clear legibility of the message.
- The minimal level of luminance necessary for clear legibility had to be equal to or greater than 1 cd/m^2 for the background and 3.5 cd/m^2 for the legend as seen in Table 1.
- In the literature review, the researchers of illuminated overhead signs by vehicle headlights tend to differ on the precise minimal luminance levels. The levels range from 1.3 cd/m^2 by Forbes [3] to as high as 70 cd/m^2 by Lewin [7]. The reason for such variations basically stem from two reasons:
 - 1/ the number of variables considered for the assessment of legibility, and
 - 2/ The method selected to derive the relationships between the variable.

It seems that when the relationships are derived with an empirical approach, the minimal luminance estimates tend to be of lower magnitude ranges, and tend to be closer to the field observations. However, if the

relationships are based on theoretical techniques the minimal luminance estimates tend to be higher in magnitude.

- In the course of luminance measurements, the test vehicle was located on the shoulder of the highway, which is not the best location for proper illumination of an overhead sign. However, the increase in luminance reading was significantly higher when the low beam headlights were turned on than when the sign was illuminated by platoons of moving vehicles and other illumination. This observation demonstrates the ability of the retro-reflective material to reflect most of the illumination back towards the light source within a narrow cone, regardless of variability in the angle of incidence.

This characteristic of retro-reflective materials has not been given enough weight in current MTC illumination practice, but should be of vital importance. Elstad et al [2], Forbes et al [3], Olson et al [8], Rizenbergs [11], Woods et al [14], and Youngblood [15] have investigated the benefits of retro-reflective materials and conclusively illustrate that signs with retro-reflective sheeting, especially those with spherical glass beads, produce the strongest luminance in the direction of a light source, such as the headlights of an approaching vehicle, and do not require other illumination.

- It was observed that with some illuminated signs, and signs with high ambient illumination, the legibility of the message was poor. Upon further investigation it was established that the legibility difficulties were caused by the following conditions:

- 1/ The highway lighting was located in relation to the sign in a way which produced either glare patches on the sign or created very high background luminance. Both of these conditions reduce contrast. The first reduces contrast between the legend and the background while the second reduces contrast between the sign and its surrounding.

Forbes et al [3], Olson et al [8] and Youngblood [15] have stressed that both these contrasts are major factors in providing good legibility and awareness of an approaching sign.

- 2/ At some signs the headlights of the test vehicle produced

negligible increase in the luminance level. This condition was caused by improper location of the sign relative to the alignment of the roadway. Olson et al [8] has demonstrated that the roadway alignment is an important factor which affects the legibility distance of an overhead sign. In his computer model for determining legibility distances of overhead signs, Olson included the roadway alignment as one of the main input parameters.

Thus, the low values of luminance for good visibility (1 to 1.3 cd/m^2), as quoted above, depend on even illumination, good contrast, and perpendicularity of the sign to the road axis.

5/ CONCLUSIONS AND SUGGESTED RESEARCH

In presenting the following conclusions it is important to understand that they are offered in the context of the investigation presented.

The authors realize that legibility is determined to a great extent by factors other than those investigated in this report. Most of the excluded areas have been adequately investigated by other researchers.

Furthermore, since the conclusions presented here have been based on a set of assumptions which were formulated in part on the findings of others, it must be understood that modification or revisions of such findings could also affect these conclusions.

5.1/ Conclusions

- 1/ Based on the current literature and field investigations it has been demonstrated that the illumination of retro-reflective overhead signs should be discontinued. Because of unfavourable locations vis-a-vis road alignment or other requirements, some overhead signs may need supplementary lighting; however, such exceptions should be considered on an individual basis.
- 2/ The luminance levels for retro-reflective overhead signs should not be less than 1 cd/m^2 for the background and 3.5 cd/m^2 for the legend, when the sign is illuminated by the low beams of one moving vehicle from a distance of 100 m. The combination of legibility factors within the design standards of overhead signs should be arranged in such combinations to reflect these requirements.
- 3/ Because the legibility of signs is dependent on a multitude of inter-related and variable factors, the designing of signs can become a costly and resource-consuming procedure. For this reason, the implementation of computer techniques becomes an attractive and inevitable solution for legibility estimates and placement of overhead signs. In fact, development of such modelling capability has been undertaken by some researchers; for example, Olson and Bernstein [8] are in the process of finalizing a computer model for the assessment

of legibility distance. Consequently, in order to provide a capability for designing vehicle illuminated overhead signs for MTC use, the acquisition of existing packages, such as that developed by Olson et al, or the development of a similar model, should be undertaken by Research and Development without undue delay.

4/ Finally, there are several legibility factor relationships which have not been well defined and are unavailable, but which are essential for the establishment of legibility parameters for vehicle illuminated overhead signs. The following relationships must be determined in order to provide a reliable procedure for estimation of overhead sign legibility:

- a/ illuminance and luminance relationships produced by the variation of the distance from the sign and by the variation in the directional intensity of headlight dispersion for different vehicle types;
- b/ relationship between the directional retro-reflective intensity for the variations in the incidental illumination; and
- c/ establishment of the minimal luminosity levels for various contrast requirements and colour combinations for different operating conditions (urban or rural). Also, identification of potential exceptions where supplementary illumination becomes an essential requirement.

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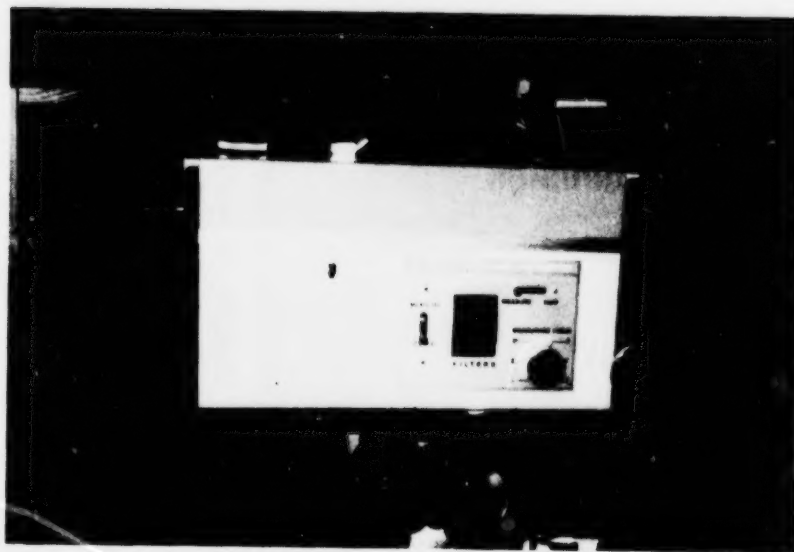
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Table 1/ LUMINANCE MEASUREMENTS AND VISUAL ASSESSMENT

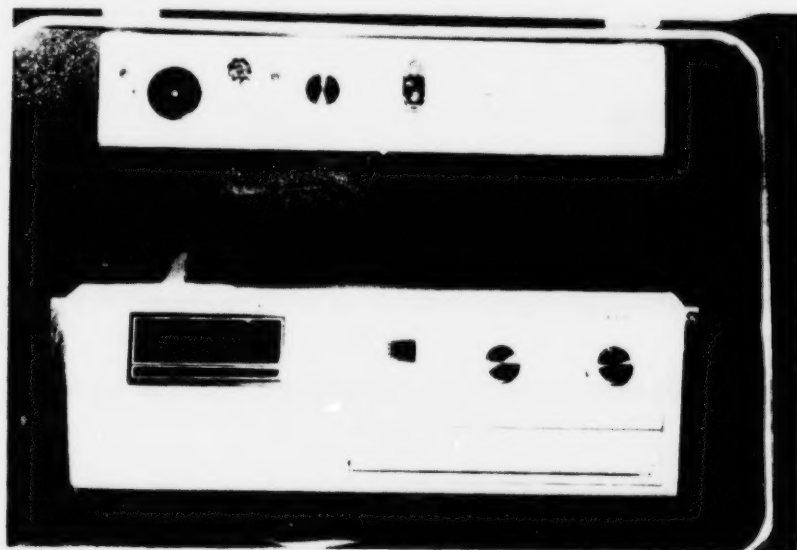
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	C O L O U R	S I G N V I S I B I L I T Y	S I G N L U M I N A N C E (c d / m)			S I G N V I S I B I L I T Y	S I G N L U M I N A N C E (c d / m)	
			B A C K G R O U N D	L E G E N D	C O N T R A S T %		B A C K G R O U N D	C O N T R A S T
1L**	B	GOOD	1.24	15.46	92	GOOD	1.64	20.34 92
1R**	B	GOOD	0.82	14.92	95	GOOD	1.46	20.48 93
2*	G	POOR	0.58	1.64	65	FAIR	1.84	5.28 65
3	G	POOR	0.24	0.74	68	FAIR	1.20	3.92 69
4**	B	GOOD	1.00	10.18	90	GOOD	1.86	17.40 89
5**	B	FAIR	0.60	5.00	88	GOOD	1.16	10.24 89
6	G	POOR	0.62	1.46	59	FAIR	2.02	6.50 70
7**	G	FAIR	1.96	5.70	66	GOOD	3.88	13.06 70
8	G	POOR	0.18	0.50	64	GOOD	0.88	5.28 83
9L	G	POOR	0.06	0.20	70	FAIR	1.40	3.64 62
9R	G	POOR	0.08	0.30	73	GOOD	1.42	7.64 81

** Fully illuminated sign * Partially illuminated sign Background Colour: B-blue G-green

Figure 1/ Spectra Pritchard Photometer, Model 1982



Camera



Auto-Comp™ Direct Readout System

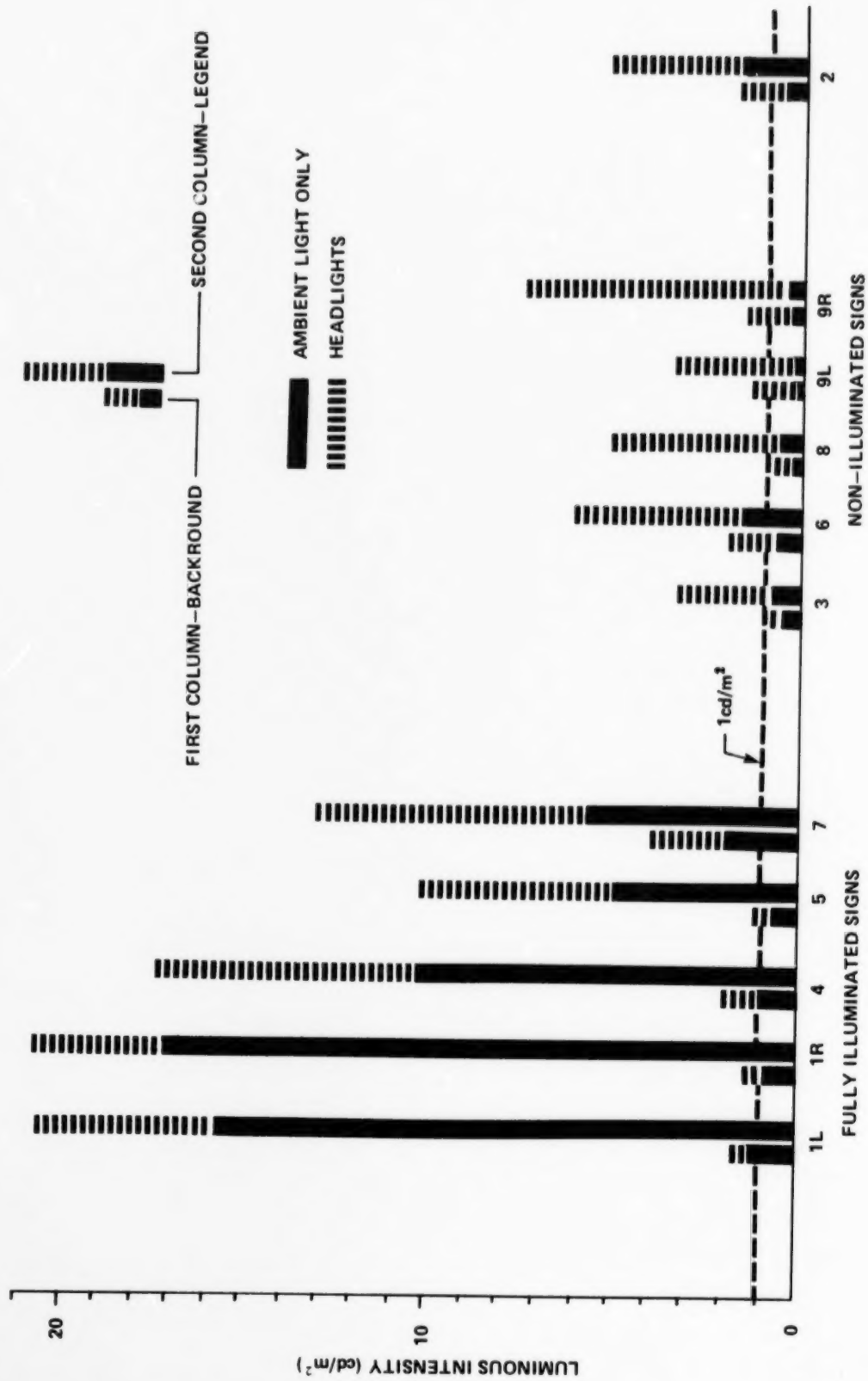
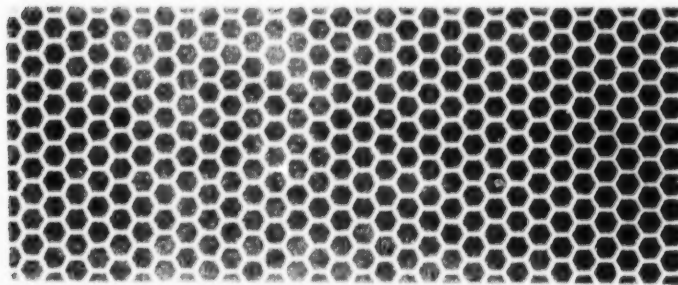
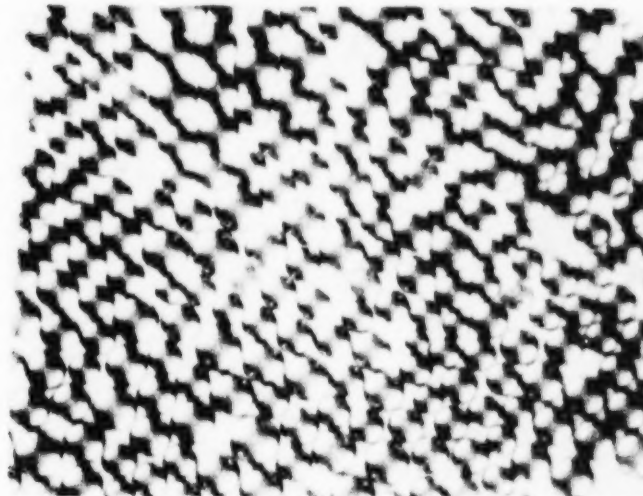


Figure 2/ Luminance Levels

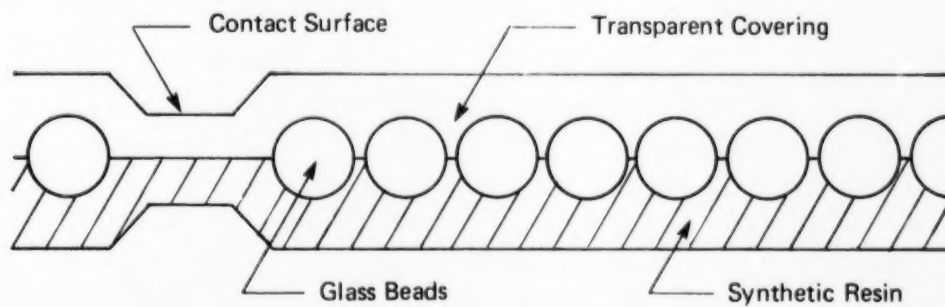
Figure 3/ High Intensity Grade "SCOTCHLITE" Sheet



3a/ Silver-white high intensity grade series 2870, 3870, 5870



3b/ 100 time enlargement of centre of one hexagon of Fig. 3a



3c/ Schematic Cross-Section



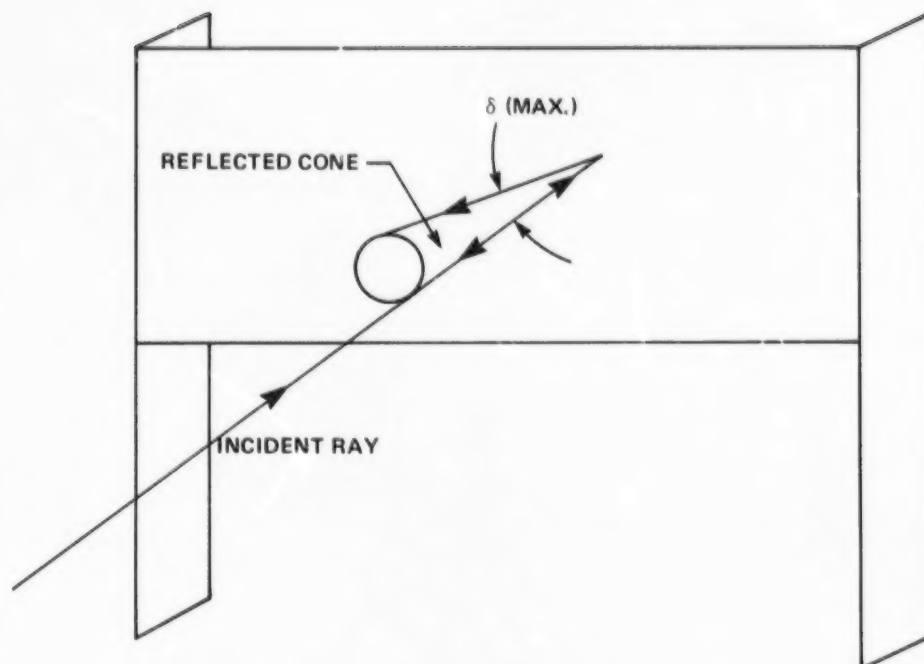


Figure 5/ Typical Reflection

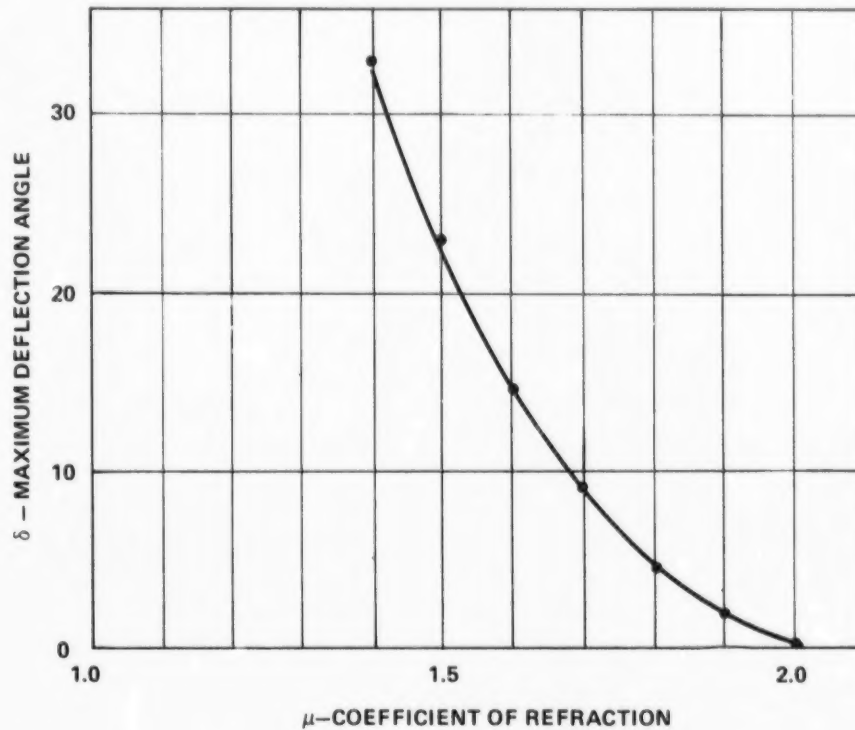


Figure 6/ Relationship Between Index of Refraction and Angle of Deflection

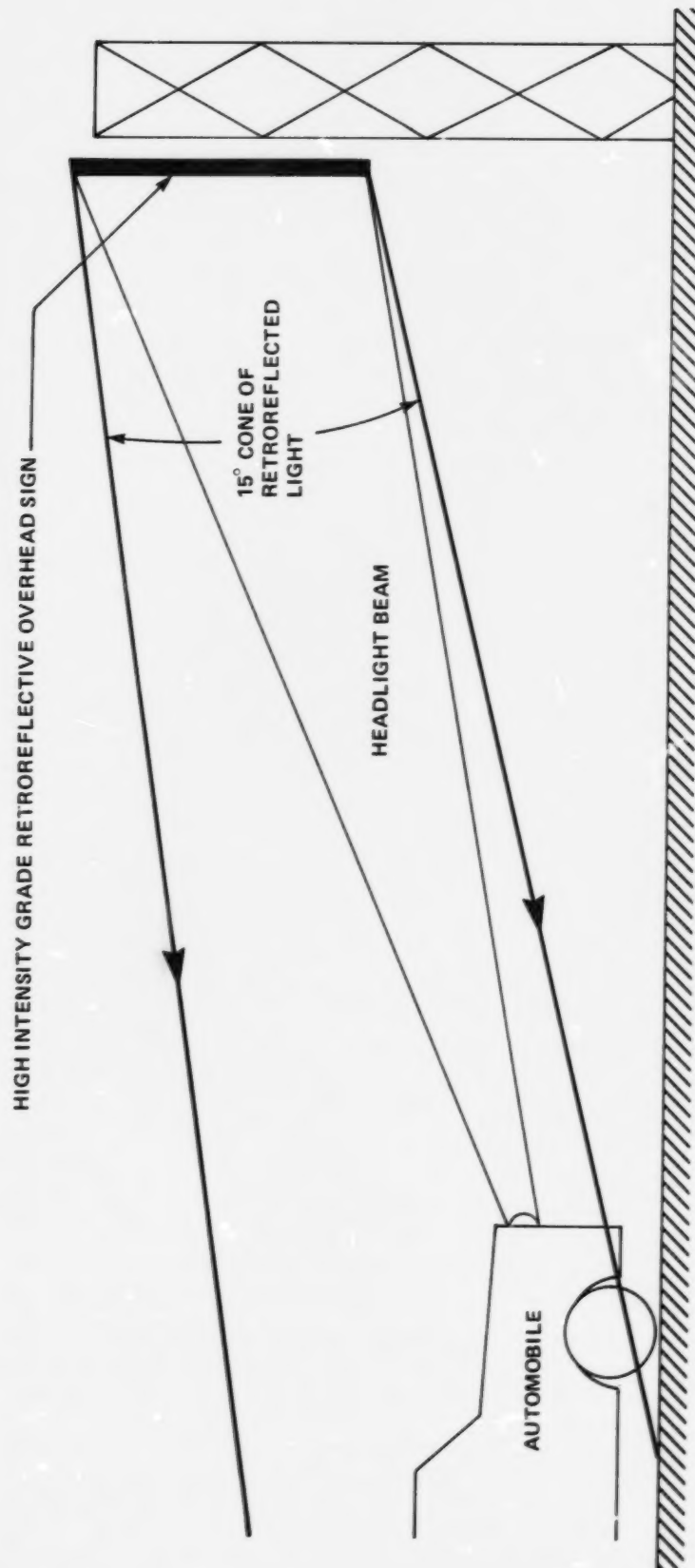
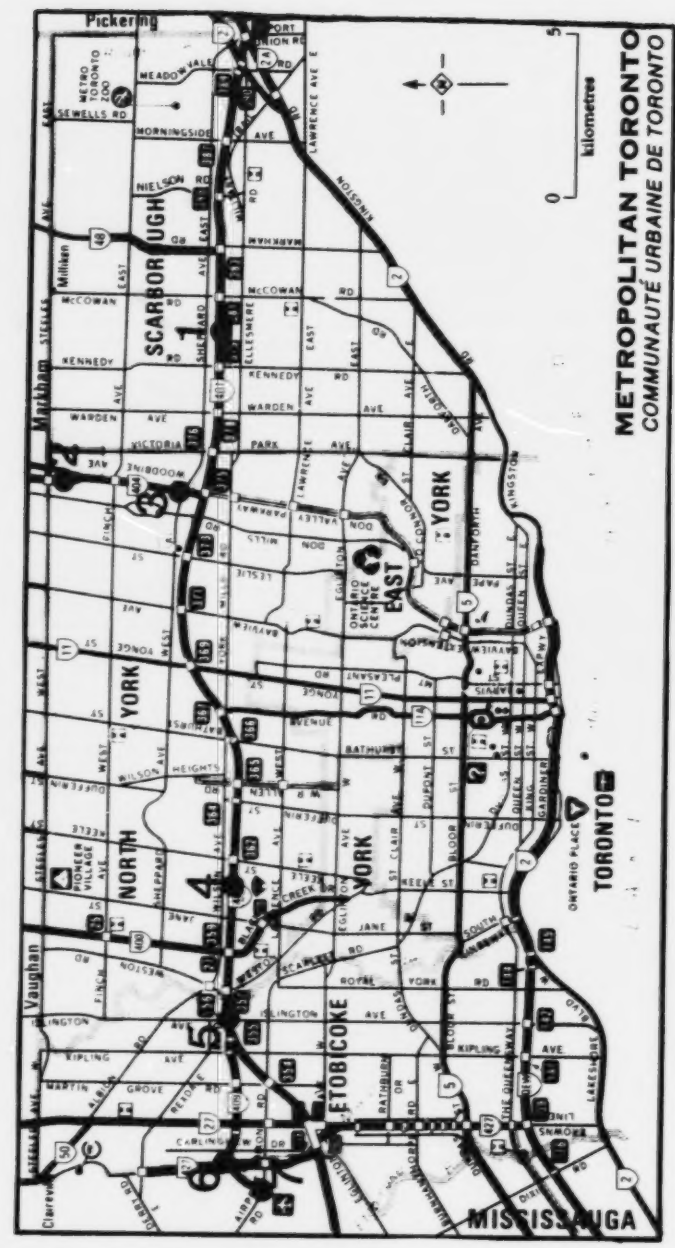
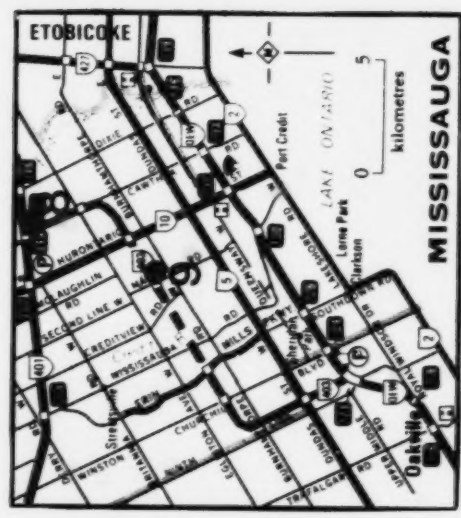


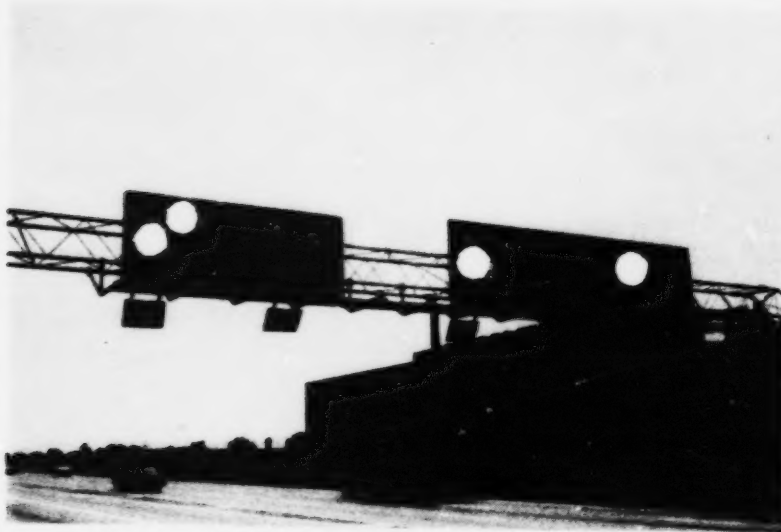
Figure 7/ Retro-reflective Signs

APPENDIX A/ Sign Descriptions and Locations

SIGN LOCATIONS



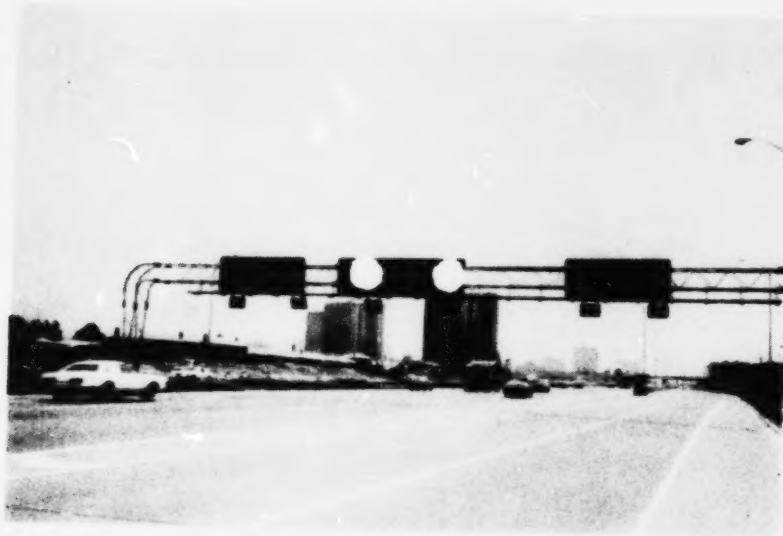
SIGN 1/ Highway 401 eastbound at transfer lanes, collector to core,
west of highway 48



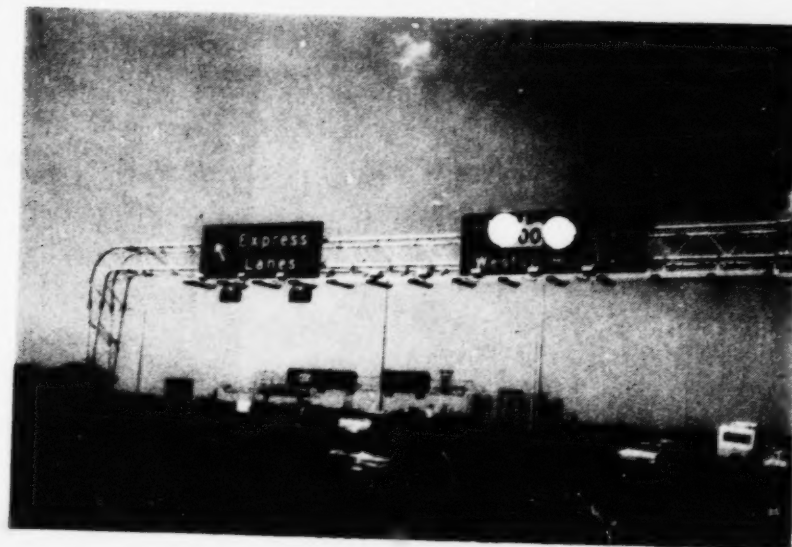
SIGN 2/ Highway 404 northbound at Steeles Avenue



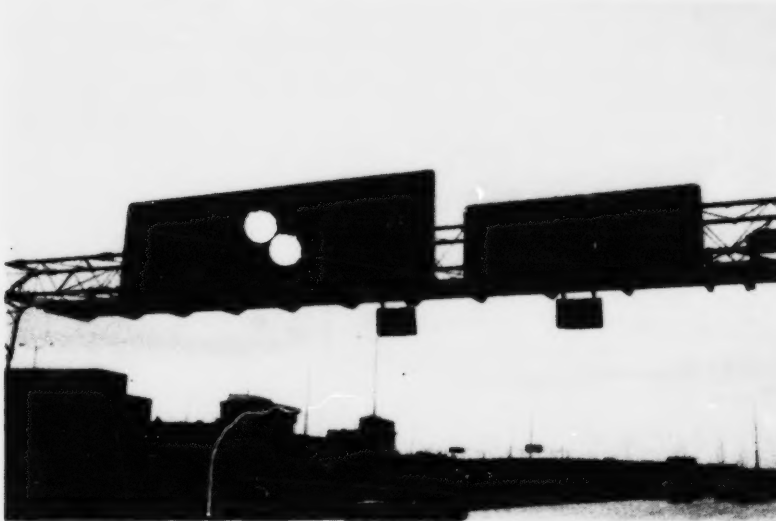
SIGN 3/ Highway 404 southbound at Sheppard Avenue



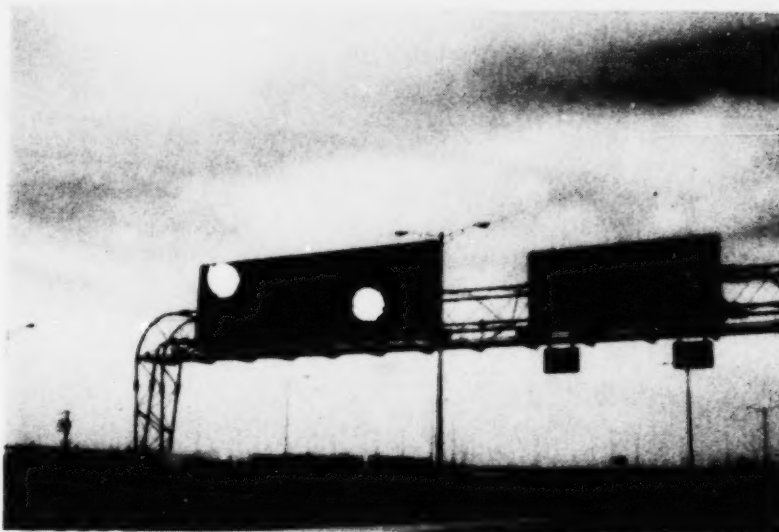
SIGN 4/ Highway 401 westbound collector lanes at the basketweave to the highway core lanes westbound



SIGN 5/ Highway 401 westbound collector lanes at Islington Ave. ramp



SIGN 6/ Highway 409 westbound at Highway 427 northbound ramp



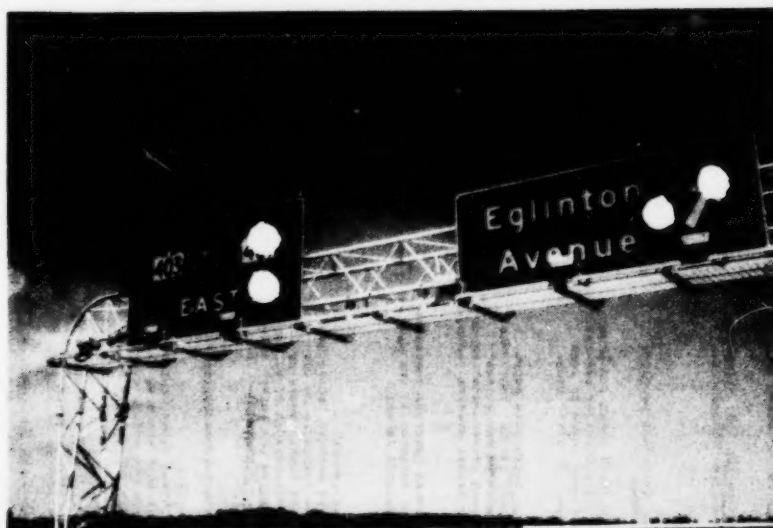
SIGN 7/ Highway 409 westbound at Airport Rd. northbound ramp



SIGN 8/ Highway 403 southbound at the advance sign for Cawthra Rd. ramp



SIGN 9/ Highway 403 northbound at Eglinton Ave. ramp



APPENDIX B/ Summary of the Literature Review

AUTHOR		YEAR	TECHNIQUE	VARIABLES	FINDINGS	COMMENTS
ALLEN et al		1967	Field Legibility Measurements	Luminance, ambient levels contrast, contrast direction, letter height, subject age	Best legibility at 20 ft-1. For low and medium ambient. Best legibility at 200 ft-1 for high ambient conditions.	The signs were internally illuminated, i.e., background was diffused glass or other such material.
ELSTAD et al		1962	Analytical plus Confirmed Measurement	Sign position, distance, road geometry, headlight beam	With high beams all materials are close to optimum zone. Low beams provide less optimum luminance of reflective materials providing adequate brightness for good legibility of traffic signs in rural and urban environment.	This analysis into iso-divergence changes through approach distance does not provide enough documentation, which would be pertinent data.
FORBES et al		1975	Laboratory Study and Field Validation	Luminance, colour contrast, sign size	Presents family of curves showing relationship of variables under investigation. The legibility distance increases as luminance and contrast increases through range tested.	A thorough study.
HARR et al		1969	Field Measurement of Luminance	Luminance, ambient levels, contrast, lettering height	Large numbers of signs were not legible under low-beams. Night brightness was highly variable, detection of signs is adversely affected by ambient brightness. Low legend-panel contrast adversely affected visibility.	No mention on what type of signs, i.e., retroreflective or not.
LEIGH		1976	Inventory of British Illumination Standards	Illuminance, luminance Illuminance-luminance ratios	Documentation of tables and recommendations.	The report discusses CIE Committee recommendations, and suggests for British standards to incorporate CIE report.
LEWIN		1974	Laboratory Study	Luminance, viewing time, contrast, illuminance, object size, disability glare, sign face material. Angle of incidence and angle of viewing	Luminance levels are suggested for rural, urban and downtown areas also relationship equations are provided between candle power, angle of incidence and distance for luminance to the point on the sign. Contrast between legend and background is an important factor.	Luminance and illuminance are based on sign luminance as the author points out that the luminance of the sign is directed towards the source and since the source is at 45° to the sign the maximum luminance is in that direction and not towards the driver.
JUNG et al		1981	Laboratory Investigation	Luminance, luminance types Arrangement of luminaires	Luminance angle of 10°, mercury vapour performs better because of uniformity, for WTC colour combinations luminance contrast increases when changed to RPS.	Developed program is not completed and thus cannot be utilized.
OLSON et al		1977	Laboratory Study and Field Validation of Computer Model	Luminance, contrast, colour sign material roadway geometrics, legibility distance	High reflective materials permit greater legibility distance, retroflected backgrounds reduce the effect of change in viewing conditions. Contrast is a very important factor, luminance requirements are lowest of reflective background.	
RISBERG		1974	Field Observations and Lab Tests	Luminance, durability, cost	The encapsulated lens sheeting, i.e., high-intensity grade materials were found to have outstanding performance. This material significantly enhances sign legibility under low beam illumination.	
STOCKTON et al		1976	Analysis and Field Observation	Traffic, geometric of roadway distance, sign size, cost speed	Need for re-evaluation of signs and markings on low rural roads.	Not significant input obtained. Utilization of road geometrics could be useful.
Roadway Sign Lighting Subcommittee		1974	Inventory	Luminance, illuminance color, ambient illumination	The report points out practical application of basic lighting principles for sign illumination.	
WOOD et al		1976	Field Legibility Measurement	Sign reflectance, mounting height, headlamp beam, sign tilt, speed	Legibility distance less with low beams for highly reflective material than for illuminated sign (10% less with low beams, 5% more with high beams). All legibility distances exceed 180 m minimum which would affect traffic operations.	The experimental design methodology utilizes a set of variables which are obtained through a regression type method. This approach would need more scrutiny.
YOUNGBLOOD et al		1971	Photometric Survey	Distance, sign position, sign material, surround headlight beams	Low beams provide average luminance in the range specified by other investigators as necessary for satisfactory legibility. Many current retro-reflective signs exhibit satisfactory low beam luminance.	

